APPLICATION UNDER UNITED STATES PATENT LAWS

Atty. Dkt. No.   <u>PW 305337</u>
<div style="text-align:center">(M#)</div>

Invention: BALANCED POSITIONING SYSTEM FOR USE IN LITHOGRAPHIC APPARATUS

Inventor (s):   KWAN, Yim Bun Patrick

For correspondence Address

||||||||||||||||||||||

00909

Pillsbury Winthrop LLP

This is a:

☐ Provisional Application

☐ Regular Utility Application

☒ Continuing Application
  ☒ The contents of the parent are incorporated by reference

☐ PCT National Phase Application

☐ Design Application

☐ Reissue Application

☐ Plant Application

☐ Substitute Specification
<u>Sub. Spec</u> Filed _____
          in App. No. ___/_____

☐ <u>Marked up Specification re</u>
Sub. Spec. filed _____
          In App. No ___/_____

SPECIFICATION

BALANCED POSITIONING SYSTEM
FOR USE IN LITHOGRAPHIC APPARATUS

[0001]   This is a continuation application of U.S. Application No. 10/209,926, filed August 2, 2002, which is a continuation application of U.S. Application No. 09/739,098, filed December 19, 2000, which is now U.S. Patent 6,449,030, which claims priority from European Patent application No. 99310371.2, filed December 21, 1999, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1.   Field of the Invention

[0002]   The present invention relates to balanced positioning systems. More particularly, the invention relates to such systems in lithographic projection apparatus comprising:

[0003]   a radiation system for supplying a projection beam of radiation;

[0004]   a first object table for holding a mask;

[0005]   a second object table for holding a substrate; and

[0006]   a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate.

2.   Discussion of Related Art

[0007]   For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam of radiation, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple stage" devices

the additional tables may be used in parallel, or preparatory steps may be carried out on one or more stages while one or more other stages are being used for exposures. Twin stage lithographic apparatus are described in International Patent Applications WO 98/28665 and WO 98/40791, for example.

[0008]   Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (comprising one or more dies) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions which are successively irradiated via the mask, one at a time. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion at once; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus—which is commonly referred to as a step-and-scan apparatus—each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

[0009]   In a lithographic apparatus, reactions on the machine frame to acceleration forces used to position the mask (reticle) and substrate (wafer) to nanometer accuracies are a major cause of vibration, impairing the accuracy of the apparatus. To minimise the effects of vibrations, it is possible to provide an isolated metrology frame on which all position sensing devices are mounted, and to channel all reaction forces to a so-called force or reaction frame that is separated from the remainder of the apparatus.

[0010]   US 5,208,497 describes a system in which the reaction of the driving force is channeled to a balance mass which is normally heavier than the driven mass and which is free to move relative to the remainder of the apparatus. The reaction force

is spent in accelerating the balance mass and does not significantly affect the remainder of the apparatus. However, the concept disclosed in US 5,208,497 is only effective for reaction forces in one direction and is not readily extendable to systems having multiple degrees of freedom. Balance masses moveable in three degrees of freedom in a plane are described in WO 98/40791 and WO 98/28665 (mentioned above).

[0011] EP-A-0,557,100 describes a system which relies on actively driving two masses in opposite directions so that the reaction forces are equal and opposite and so cancel out. The system described operates in two dimensions but the active positioning of the balance mass necessitates a second positioning system of equal quality and capability to that driving the primary object.

[0012] None of the above systems is particularly effective at counteracting yawing moments which may be induced by adjustments of the rotational position of the driven mass or because of misalignment between the line of action of forces exerted on the driven body and its center of mass.

[0013] US 5, 815,246 discloses a positioning system having a first balance mass free to move in an XY plane, i.e. to translate in X and Y and rotate about axes parallel to the Z direction. To control rotation of the first balance mass, a fly wheel, forming a second balance mass, is driven by a rotation motor mounted on the first balance mass to exert a counter-acting torque. Controlling rotation of the first balance mass therefore requires accurate control of the rotation and the flywheel. Any delay in this control or imbalance of the flywheel will cause vibration.

SUMMARY OF THE INVENTION

[0014] An object of the present invention is to provide an improved balanced positioning system for counteracting yawing moments in the driven mass and preferably also force balancing in at least two translational degrees of freedom.

[0015] According to the present invention there is provided a lithographic projection apparatus comprising:

[0016] a radiation system for supplying a projection beam of radiation;

[0017] a first object table for holding a mask;

[0018] a second object table for holding a substrate;

[0019]   a projection system for imaging irradiated portions of the mask onto target portions of the substrate; characterized by:

[0020]   a balanced positioning system for positioning at least one of said object tables and comprising:

[0021]   first and second balance masses;

[0022]   bearing means for supporting said first and second balance masses so as to be substantially free to translate in at least one direction; and

[0023]   driving means for acting directly between said one object table and said first and second balance masses to rotate said object table about an axis perpendicular to said one direction, said driving means being arranged to exert linear forces on said first and second balance masses in opposite directions to effect said rotation of said object table.

[0024]   By providing two balance masses that can translate in at least one direction, the torque required to drive the object table to adjust its rotational position, or to compensate for torques induced by other driving forces can be provided as the sum of two linearly acting forces acting between the object table and the two balance masses. The reaction forces on the two balance masses will cause them to move linearly, which can easily be accommodated. In other words, the reaction to a torque exerted on the driven object table is converted to translations of the two balance masses and no rotational movement of the balance mass occurs. It will be appreciated that if a rotational motion of the object table is combined with a linear motion, the net forces acting on each balance mass may be in the same direction, though different in magnitude.

[0025]   According to a yet further aspect of the invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:

[0026]   a radiation system for supplying a projection beam of radiation;

[0027]   a first object table for holding a mask;

[0028]   a second object table for holding a substrate; and

[0029]   a projection system for imaging irradiated portions of the mask onto target portions of the substrate; the method comprising the steps of:

[0030]   providing a mask bearing a pattern to said first object table;

[0031]   providing a substrate provided with a radiation-sensitive layer to said second object table;

[0032]   irradiating portions of the mask and imaging said irradiated portions of the mask onto said target portions of said substrate; characterized in that:

[0033]   at least one of said object tables is positioned using a positioning system which includes first and second balance masses free to move in at least one direction and drive means acting between said one object table and said balance masses; and

[0034]   during or prior to said irradiating step said one object table is rotated by exerting oppositely directed forces between it and said first and second balance masses.

[0035]   In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

[0036]   Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels,

thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0037]   In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. at a wavelength of 365nm, 248 nm, 193 nm, 157nm or 126nm), EUV, X-rays, electrons and ions.

[0038]   Embodiments of the present invention are described below making reference to a Cartesian coordinate system with axes denoted X, Y and Z in which the XY plane is parallel to the nominal substrate and reticle surfaces. The notation Ri is used to denote rotation about an axis parallel to the I direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039]   The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

[0040]   Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

[0041]   Figure 2 is a plan view of the reticle stage of the apparatus of Figure 1;

[0042]   Figure 3 is an end view of the reticle stage of the apparatus of Figure 1;

[0043]   Figure 4 is a diagram of a servo control mechanism used in the first embodiment of the present invention;

[0044]   Figure 5 is a plan view of the reticle stage of a second embodiment of the invention;

[0045]   Figure 6 is an end view of the reticle stage of the second embodiment of the invention;

[0046]   Figure 7 is a plan view of the reticle stage of a third embodiment of the invention;

[0047]   Figure 8 is an end view of the reticle stage of the third embodiment of the invention; and

[0048]   Figures 9 and 9A show a cable ducting device useable in embodiments of the invention.

[0049]   In the drawings, like reference numerals indicate like parts.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Embodiment 1

[0050]   Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

[0051]   ·   a radiation system LA, IL for supplying a projection beam PB of radiation (e.g. UV or EUV radiation, x-rays, electrons or ions);

[0052]   ·   a first object table (mask table) MT for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

[0053]   ·   a second object table (substrate table) WT for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;

[0054]   ·   a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto a target portion C (comprising one or more dies) of the substrate W.

[0055]   As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

[0056]   The radiation system comprises a source LA (e.g. a Hg lamp, excimer laser, an undulator provided around the path of an electron beam in a storage ring or synchrotron, or an electron or ion beam source) which produces a beam of radiation. This beam is caused to traverse various optical components comprised in the illumination system IL, — e.g. beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB has a desired shape and intensity throughout its cross-section.

[0057]   The beam PB subsequently intercepts the mask MA which held on a mask table MT. Having traversed the mask MA, the beam PB is caused to traverse the

lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the interferometric displacement measuring means IF, the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. The reference signs M1, M2 correspond to reticle alignment marks and the references P1 and P2 correspond to wafer alignment marks. These marks are used to align the wafer and the reticle respective to each other. In general, movement of the object tables MT, WT can be realized with the aid of a long stroke module (coarse positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1.

[0058]   The depicted apparatus can be used in two different modes:

[0059]   1.   In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected at once (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

[0060]   2.   In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given reference direction (the so-called "scan direction", *e.g.* the Y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0061]   Figures 2 and 3 show the reticle (mask) stage of the first embodiment of the invention in greater detail. The mask MA (not shown in Figure 2), whose pattern is to be imaged onto the wafer, is held on mask table MT. To accommodate the scan mode of the apparatus the mask must be positioned accurately over a relatively wide range of movement (stroke) in the Y direction but only over much smaller ranges of movement in the other degrees of freedom. This large Y-direction stroke, as well as a more limited stroke in the X-direction and some Rz movement, is effected by the long stroke (coarse positioning) module described below. Fine positioning in all six degrees

of freedom is accomplished by shortstroke position actuators included in the mask table.

[0062]   Mask table MT depicted in Figures 2 and 3 is intended for use with transmissive masks which means that the space above and below it must be kept clear. Accordingly, mask table MT is supported from two balance masses 20, 30 positioned either side of a clear space extending in the Y-direction. In the present embodiment, three beams 11, 12, 13, which extend transversely from mask table MT, are provided for this purpose but the beams may alternatively be formed integrally with the body of mask table MT or the mask table may itself extend over the balance masses 20, 30. Balance masses 20, 30 have parallel planar upper surfaces against which table bearings 14, 15, 16 provided on the ends of beams 11, 12, 13 act to support the mask table. Table bearings 14, 15, 16 allow mask table MT to move in the XY plane relative to balance masses 20, 30 substantially without friction. Table bearings 14, 15, 16 may, for example, be gas bearings. Z-direction actuators may also be included in these bearings for coarse positioning in Z, Rx and Ry.

[0063]   Balance masses 20, 30 are supported by substantially frictionless Z-bearings 21, 22, 23, 31, 32, 33 on parallel rails 40, 50 which extend in the Y-direction and may be part of or connected to the main machine frame, or base plate, BP. Rails 40, 50 have substantially flat horizontal upper surfaces 41, 51 against which Z-bearings 21, 22, 23, 31, 32, 33 act so that the balance masses 20, 30 are free to move in the Y-direction over a relatively wide range of motion. Z-bearings 21, 22, 23, 31, 32, 33 may be compliant, i.e. have a low stiffness, in the Z-direction so that the balance masses 20, 30 are also substantially free to move in the Z-direction, though over a much smaller range of movement. Freedom for the balance masses to move in the X-direction may be similarly provided by compliant X-bearings 24, 25, 34, 35 acting against substantially planar vertical walls 42, 52 of the rails 40, 50. X-bearings 24, 25, 34, 25 may be preloaded or opposed pad bearings to exert forces in both directions. Z-bearings 21, 22, 23, 31, 32, 33 and X-bearings 24, 25, 34, 35 may be, for example, gas bearings. The balance masses 20, 30 are thus free to move in all three translational degrees of freedom and so provide balancing to the mask table in those directions. Rotational balancing in Rx and Ry is provided because the Z-bearings 21, 22, 23, 31, 32, 33 can be moved independently and are spaced apart. Balancing for Ry movements

is provided by differentially driving the two balance masses 20, 30, as is discussed below.

[0064]   If the ranges of movement of the mask table in the degrees of freedom other than Y translation are small, as is the case in the present embodiment, the necessary freedom of movement of the balance masses can also be accommodated by leaf spring arrangements, compliant bearings or other stiff bearings in combination with a gravity compensator. It is also possible to arrange that reaction forces in some or all of the other degrees of freedom are only transmitted to one of the balance masses so that only that balance mass needs to be supported with controlled compliance in the relevant degrees of freedom.

[0065]   The stiffness of the bearings or supports in the other degrees of freedom and the mass of the balance mass(es) form a mass-spring system that acts as a low-pass filter, i.e. only low frequency forces are transmitted to the machine frame. Significant attenuation of the reaction forces can be obtained if the natural frequency of this mass-spring system is substantially, for example 5 to 50 times, lower than the fundamental frequency of the actuation forces.

[0066]   As will be described below, the mask table MT is driven by actuators acting against the balance masses 20, 30 so that they accelerate in the opposite direction to the mask table MT. The magnitudes of the accelerations of the balance masses and the mask table MT will be proportional to their masses and so the ranges of movement of the balance masses and the mask table in the various directions must be in the ratio of their masses. To reduce the ranges of movement that must be provided for the balance masses 20, 30 to accommodate the desired ranges of movement of the mask table MT, the balance masses 20, 30 are made relatively massive, e.g. each 2 to 10 times the mass of the mask table MT. The centers of mass of the balancing masses 20, 30 and mask table MT are preferably as close as possible in the Z-direction, e.g. substantially less than 100 mm, in order to minimise pitching or rolling moments.

[0067]   In the present embodiment, the mask table MT is driven in the Y-direction by Y1-drive 18 acting between it and balance mass 20 and Y2-drive 17 acting between it and balance mass 30. Y1- and Y2-drives 17, 18 may, for example, comprise linear motors with an armature mounted to the mask table MT and an elongate stator mounted to the respective balance mass. Yi-drive exerts, in operation, a force F_{yi} on

the mask table MT and an equal and opposite reaction force R_{yi} on the respective balance mass.

[0068] Positioning in the X-direction is effected by a single X-actuator 19 acting against balance mass 30. X-actuator 19 may also be a linear motor with armature mounted to the mask table and stator mounted to the balance mass or may be an elongated voice-coil motor free to displace in the Y-direction, or a cylindrical voice-coil motor coupled to an aerostatic bearing that bears against a surface parallel to the YZ plane. To enable the mask table to be driven in the X-direction whatever the relative Y position of the mask table MT and balance mass 30, if X-actuator is a linear motor, the stator must extend the whole of the combined range of movement of the balance mass and mask table in the Y direction. The line of action of the X-actuator 19 is preferably arranged to pass through at least the Y-position of the center of gravity CG_{MT} of the mask table MT so as to minimise the generation of Rz moments.

[0069] It follows from Newton's laws that if there is no rotational movement of the mask table, the displacements Δy_{b1}, Δy_{b2} and Δy_{MT} of the balance masses 20, 30 and mask table MT satisfy the following conditions:

$$\frac{\Delta y_{MT}}{\Delta y_{b1}} = -\frac{m_{b1}}{m_{MT}} \cdot \frac{l_1 + l_2}{l_2} ; \frac{\Delta y_{MT}}{\Delta y_{b2}} = -\frac{m_{b2}}{m_{MT}} \cdot \frac{l_1 + l_2}{l_2} \qquad [1]$$

where:

[0070] l_1 and l_2 are respectively the distances in the X-direction between the centers of gravity CG_{B1}, CG_{B2} of the balance masses 20, 30 and the center of gravity CG_{MT} of the mask table MT; and

[0071] m_{b1}, m_{b2} and m_{MT} are the masses of the balance masses 20, 30 and mask table MT.

[0072] If $m_{b1} = m_{b2} = m_b$ and $l_1 = l_2$, then equation 1 can be reduced to:

$$\Delta y_{b1} = \Delta y_{b2} = -\Delta y_{MT} \cdot \frac{m_{MT}}{2m_b} \qquad [2]$$

[0073] To effect a yawing (Rz) movement of the mask stage whilst still containing the reaction forces within the balance mass system, the forces applied by

Y1- and Y2-drives 17, 18 are controlled to take advantage of D'Alambert forces by moving the balance masses in opposite directions. Note that if the yawing motion is effected at the same time as a movement in Y, the balance masses may move in the same direction but by differing amounts, thus the movement in opposite directions is relative rather than absolute. For a counter-clockwise movement of the mask stage by an angle θ_{MT} the necessary relative movements of the balance masses are given by:

$$\Delta y_{b1} = -\frac{J_{MT} \cdot \theta_{MT}}{(l_1 + l_2) \cdot m_1}; \Delta y_{b2} = -\frac{J_{MT} \cdot \theta_{MT}}{(l_1 + l_2) \cdot m_2} \qquad [3]$$

[0074]   where J_{MT} is the moment of inertia of the mask table MT.

[0075]   It should be noted that the present invention does not require the masses of the first and second balance masses to be equal nor that they be disposed equidistantly about the centre of gravity of the mask table.

[0076]   In a perfect, closed system, the combined center of mass of the mask table MT and balance masses 20, 30 will be stationary, however it is preferable to provide a negative feedback servo system to correct long-term cumulative translations (drift) of the balance masses that might arise from such factors as: cabling to the mask table and drives, misalignment of the drives, minute friction in the bearings, the apparatus not being perfectly horizontal, etc.. As an alternative to the active drift control system described below, a passive system, e.g. based on low-stiffness springs, may be used.

[0077]   Figure 4 shows the control loop of the servo system 130. The Y and Rz setpoints of the balance masses with respect to the machine frame are supplied to the positive input of subtractor 131, whose output is passed to the servo controller 132. Feedback to the negative input of subtractor 131 is provided by one or more multiple-degree-of-freedom measurement systems 134 which measure the positions of the balance masses and driven mass (mask table). The servo controller controls a two-degree-of-freedom actuator system 133 which applies the necessary corrections to the balance masses 20, 30. The positions of both balance masses and driven mass may be measured relative to a fixed frame of reference. Alternatively, the position of one, e.g the balance masses, may be measured relative to the reference frame and the position of the driven mass measured relative to the balance masses. In the latter case the relative

position data can be transformed to absolute position data either in software or by hardware. Particularly in the Y-direction, the position measurement may be performed by a linear encoder with a high tolerance to residual relative movements in the other degrees of freedom, such as those described in US patent 5,646,730, for example.

[0078] The set points of the servo system 130 are determined so as to ensure that the combined center of mass of the mask table MT and balance masses 20, 30 remains unchanged in the X, Y, Rz plane. This defines the condition:

$$m_{MT} \cdot \vec{u}_{MT}(t) + m_{b1} \cdot \vec{u}_{b1}(t) + m_{b2} \cdot \vec{u}_{b2}(t) =$$

$$m_{MT} \cdot \vec{u}_{MT}(0) + m_{b1} \cdot \vec{u}_{b1}(0) + m_{b2} \cdot \vec{u}_{b2}(0) \qquad [4]$$

[0079] where $\vec{u}_i(t)$ is the vector position of mass i in the X-Y plane at time t relative to a fixed reference point. The error signal between the calculated (using equation [4]) and measured positions is provided to the actuation system 133 which applies appropriate correction forces to the balance masses 20, 30. The lowest resonance mode of the balancing frame and/or machine base is preferably at least a factor of five higher than the servo bandwidth of the drift control system.

[0080] The above described servo system can be used in the Y-direction only with drift control in the other degrees of freedom being performed by the low stiffness of the supports for the balance masses in those degrees of freedom.

Embodiment 2

[0081] A second embodiment of the invention is shown in Figures 5 and 6 and is essentially the same as the first embodiment except as noted below.

[0082] The second embodiment is particularly applicable to lithographic apparatus employing reflective masks so that the space underneath the mask table MT does not need to be kept clear. Advantage is taken of this fact to support the mask table MT over a third balance mass 60. Third balance mass 60 has a planar, horizontal upper surface over which is guided the mask table MT supported by bearings 71, 72, 73. These bearings may be, for example, gas bearings. Third balance mass 60 is in turn supported over the machine base frame by compliant bearings 61, 62, 63, which may comprise low stiffness springs. The third balance mass does not move in the XY plane so can alternatively be supported by leaf springs or gas cylinders without actual

bearings. As illustrated, the second embodiment uses cylindrical voice coils 74, 75 in combination with X-bearings 76, 77 acting against the side of the second balance mass 30 for X-direction actuation. The X-bearings 76, 77 may be opposed pad bearings or preloaded so that forces in both directions can be exerted.

Embodiment 3

[0083]   In a third embodiment, shown in Figures 7 and 8 and which is the same as the first embodiment save as described below, the longstroke module positions a short, stroke frame 80 in Y and Rz only. Mask table MT is driven relative to the short stroke frame 80 to position the mask in six degrees of freedom to a high precision. Such positioning is effected by short stroke Z-actuators 81, 82, 83, X-actuator 84 and Y-actuators 85, 86. The short stroke frame 80 is supported over first and second balance masses 20, 30 by stiff Z-bearings 14', 15' 16', which may be gas bearings acting on the planar upper surface of the balance masses. Short stroke frame 80 is also constrained in X by bearing 78 relative to only one of the balance masses, in this case the second balance mass 30.

[0084]   In the Y and Rz directions, the mask table MT moves with the short, stroke frame 80 so that in equations 2 and 3 the mass and moment of inertia, m_{MT} and J_{MT}, should be replaced by the combined mass and moment of inertia of the mask table MT and short stroke frame 80. However, in the other degrees of freedom the short stroke frame 80 is constrained to move with the balance mass and so increases the effective balancing mass, reducing its stroke. The center of gravity of the mask table MT is preferably coplanar, or close to coplanar, with that of the short stroke frame 80 and balance masses 20, 30.

Embodiment 4

[0085]   A cable ducting device according to a fourth embodiment of the invention is shown in Figures 9 and 9A. Two cable ducts 151a, 151b are used to carry cables and other conduits for utilities, such as control signals and power, required by the mask table. The two cable ducts 151a, 151b are laid out in opposite directions between a terminal 152 mounted on the mask table and a terminal 153 mounted on the machine frame so that as the mask table moves in the Y direction, one cable duct is

rolling up and the other is unrolling. The total length of cable duct moving with the mask table therefore remains constant, whatever the Y position of the mask table. The moving mass therefore remains constant. Also, any residual tendencies of the cable ducts to roll up or unroll will counteract each other. The cable ducts 151a, 151b have a slightly curved cross-section, shown in Figure 9A which is a cross-sectional view along the line A-A, in the same manner as a measuring tape. This prevents sagging and helps maintain a neat "U-shape" as the mask table moves.

[0086]   Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention. In particular it will be appreciated that the invention may be used in the reticle or mask table of a lithographic apparatus and in any other type of apparatus where fast and accurate positioning of an object in a plane is desirable.

[0087]   Although this text has concentrated on lithographic apparatus and methods whereby a mask is used to pattern the radiation beam entering the projection system, it should be noted that the invention presented here should be seen in the broader context of lithographic apparatus and methods employing generic "patterning means" to pattern the said radiation beam. The term "patterning means" as here employed refers broadly to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" has also been used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device. Besides a mask on a mask table, such patterning means include the following exemplary embodiments:

[0088]   -   A programmable mirror array. An example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the

diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-adressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, which are incorporated herein by reference.

[0089]   -   A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference.